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Salt removal capacity and nutrient status of a forage cropping system based on triticale and alfalfa when grown on a salinized calcareous soil

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Managing soil salinization requires identifying a sustainable cropping system to improve soil quality by removing salts, particularly in the south Mediterranean area. The present study aimed to evaluate the efficiency of the forage crop succession containing triticale and alfalfa in removing salt from salinized calcareous soil. The experiment was conducted in field during two successive seasons. Five electrical conductivity levels of salinized soil (ECs) were tested: 0.3 (control), 0.8, 1.4, 1.8, and 2 dS m^{-1} (1:5extraction). The triticale was grown from November 2019 to April 2020. The alfalfa occupied the same soil from June 2020 to October 2021 (11cuts). The electrical conductivity of the irrigation water was ECi=1.1 dS m^{-1}. The results revealed that the soil salinity and the exchangeable sodium percentage (ESP) decreased during the cropping seasons. The high ECs=2 dS m^{-1} and its ESP=85.2% became similar to control levels (ECs=0.25 dS m^{-1}, ESP=5%) after the succession of triticale and fourth cuts of alfalfa. The NaCl uptake at the end of the cropping succession was 1433 kg ha^{-1} at an initial ECs=2 dS m^{-1}. Concerning the nutrient status of the plants, nitrogen, phosphorus, and potassium contents were invariable with ECs levels. For alfalfa, a reduction in calcium and magnesium contents was noticed with soil salinity in the first season (2020). The results suggest that the insertion of triticale and alfalfa in the forage cropping system is an efficient solution for removing salt from salinized soils to ensure sustainable agricultural production.
Keywords: Alfalfa, NaCl uptake, nutrient status, soil salinity, sustainable agriculture, triticale.

INTRODUCTION

Soil salinity is a major agricultural problem, particularly in arid and semi-arid Mediterranean regions (Aragüés *et al.*, 2011). In this context, soil quality is considered an essential element of sustainable agriculture. The challenge is to adopt sustainable management approaches to improve soil quality (Zalidis *et al.*, 2002). In Morocco, salinization affected around 500 000 ha of agricultural area (ONEDD, 2015). The soil salinization is mainly attributed to the use of saline water (Machado and Serralheiro, 2017). It resulted in soil degradation at a high exchange sodium percentage (ESP>15%) and a reduction of crop productivity and quality (Kankarla et *al.*, 2021; Dagar et *al.*, 2022), thereby affecting the sustainability of the cropping system.

The forage cropping system in Morocco suffers from salinity along with drought. The choice of salt-tolerant crops (Bhattarai *et al.*,2020; Erkan and Özlem,2021) and reasonable fertilization (Machado and Serralheiro, 2017) are the most effective strategies for reducing the effect of salinity on forage cropping system. In previous study, the introduction of salt-tolerant forages, such as blue panicum, sesbania, and pearl millet, was clearly shown a positive agronomic results and demonstrated a forage potential to replace traditional practices (Hirich *et al.*, 2021). Triticale (*Triticosecale wittm.*) is identified among the most salt-tolerant crops (Kankarla *et*

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al., 2021). The productivity and nutritional value of this forage crop led to choose it as an alternative to other cereals at salt stress conditions (Mergoum *et al.*, 2019). Nevertheless, a high soil salinity level (ECs) over than 6.1 dS m^{-1} (Saturated paste extract) (Grieve *et al.*, 2012) reduced biomass production (El-Metwally *et al.*, 2019; Alagoz *et al.*, 2021) due to the toxicity effect of sodium (Na^+) and chloride (Cl^-) and the disruption of nutrient uptake (El-Metwally *et al.*, 2019). Indeed, previous research revealed increases in Na concentrations in triticale leaves and decreases in potassium (K) at salt stress (Alagoz *et al.*, 2021). In addition, alfalfa (*Medicago sativa* L.) is a moderately salt-tolerant crop (Cornacchione and Suarez, 2017). The negative impact of salinity on the biomass yield of alfalfa was recorded at ECs > 2 dS m^{-1} (Saturated Paste Extract) (Díaz *et al.*, 2018). This crop is one of the most important forage crops due to its high protein content, digestibility, and palatability (Ferreira *et al.*, 2015). It can be introduced in a forage cropping system to remove the accumulated salts in the soil (Shah *et al.*, 2022). Cao *et al.* (2012) reported a decrease in soil electrical conductivity and salt concentration with increasing occupation time of alfalfa. Indeed, the concentration of Na, Cl, and magnesium (Mg) in alfalfa plants increased at high salinity levels. In contrast, calcium (Ca), and K concentrations decreased under salt stress (Bhattarai *et al.*, 2020).

In the south Mediterranean area, few studies assess the ability of salt-tolerant forage crops to remove salts and improve the quality of saline soils. Therefore, the present study aimed to evaluate the efficiency of the crop succession containing triticale and alfalfa in removing salt from salinated soil located in Morocco. This study also aimed to assess the nutrient status shifting of these crops in saline conditions. The studied crop succession has not been reported in the literature, and the results will help discover a new sustainable forage cropping system using reasonable fertilization.

MATERIALS AND METHODS

Experimental site and studied soil**:** A field experiment with a cropping succession of triticale (*Triticosecale wittm*.) and alfalfa (*Medicago sativa* L.) was carried out during two successive production seasons (2019-2020 and 2020-2021). Triticale (cv. Titania) was installed in the rainy season from November 2019 to April 2020 and alfalfa (cv. Melissa) was installed in June 2020 to October 2021. The experiment was carried out in the Saïs region (33.54 N, -4.41 W, 649 m Alt, North East of Morocco). The studied soil was clay-calcareous (54% clay, 28% silt, 18% sand, and 14% free carbonates) with a pH of 8.7. Other soil characteristics are reported in Table 1.

Soil Salinity treatments and experimental design**:** The tested salinity levels of the soil were obtained by the application of saline water enriched with 4 levels of NaCl: 0.7 (control without adding NaCl), 4, 6, 8, 10 dS m^{-1}. The application of each saline water level to the soil started 3 months before the sowing of crops in November. The experimental plots of 8.4 m² (4 m×2.1 m) were supplied daily with an average of 6 mm to achieve a total of 550 mm. Each experimental plot was repeated 4 times (n= 4) in the randomized complete blocks. The spacing between two adjacent experimental plots was 2 m. After the salinization period, salinity levels of soil at 0-30cm were determined. The 5 soil salinity levels obtained are 0.3 (control), 0.8, 1.4, 1.8, 2 dS m^{-1}.

Table 1. Physico-chemical properties of the experimental soil (0-30 cm).

Properties	Value
Clay (%)	53.7
Silt (%)	28.2
Sand (%)	18.1
Texture class	Clayey
pHa	8.7
Total carbonates (%)[b]	29.6
Free carbonates (%)[c]	14.0
Electrical conductivity (EC) (dS m^{-1})[a]	0.32
Cation exchange capacity (CEC) (meq $100g^{-1}$)[d]	24
Organic matter (%)[e]	3.2
Sodium (Na) (mg kg^{-1})[g]	377
Chloride (Cl) (mg kg^{-1})[a]	20.8
Phosphorus (P) (mg kg^{-1})[f]	16.2
Potassium (K) (mg kg^{-1})[g]	284.5
Magnesium (Mg) (mg kg^{-1})[g]	1231
Calcium (Ca) (mg kg^{-1})[g]	7894
Zinc (Zn) (mg kg^{-1})[h]	0.8
Iron (Fe) (mg kg^{-1})[h]	6.9
Manganese (Mn) (mg kg^{-1})[h]	4.6
Copper (Cu) (mg kg^{-1})[h]	1.5
Boron (B) (mg kg^{-1})[i]	0.5

a) Analyzed in a soil: water ration of 1:5. b) Analyzed by volumetric method. c) Analyzed by oxalate ammonium method. d) Determined using cobalthexamine chloride method. e) Determined using Walkley and Black method. f) Determined by Olsen extraction method. g) Extracted by the ammonium acetate at pH = 7. h) Determined using the DTPA extraction at pH = 7.3. i) Determined using the hot water extraction method.

Crop management**:** The sowing of triticale was carried out manually just after the soil salinization. The sowing was carried out in rows spaced 15 cm apart. The seed rate was 180 kg ha^{-1}. After the triticale harvest in June 2020, alfalfa was sown on the same experimental plots and crop lines at a rate of 30 kg ha^{-1}. Each crop line was equipped with a drip irrigation line with a flow rate of 17 mm h^{-1}, 1.2 l h^{-1} emitters and 0.1 m as spacing. The water used for irrigation was non-saline (1.1 dS m^{-1}). The tensiometers (Water Mark, Irrimeter Company, INC. Riverside, California) were installed at a 30 cm soil depth for each experimental plot to control irrigation. The rainfall and temperatures were recorded daily by a weather station (Adcon Telemetry, Austria) installed at the

experimental site (Figure 1). The average minimum and maximum temperatures during the triticale production season were 7.9°C and 18.7°C, respectively. For alfalfa, 4 cuts were performed in 2020 (from June to December) and 7 cuts in 2021 (from April to October). The average minimum and maximum temperatures of the growing seasons were, respectively, 14.7°C and 27.2°C and 12.1°C and 24.3°C in 2020 and 2021. The rainfall was 431 mm from November 2019 to December 2020 and 366 mm in 2021.

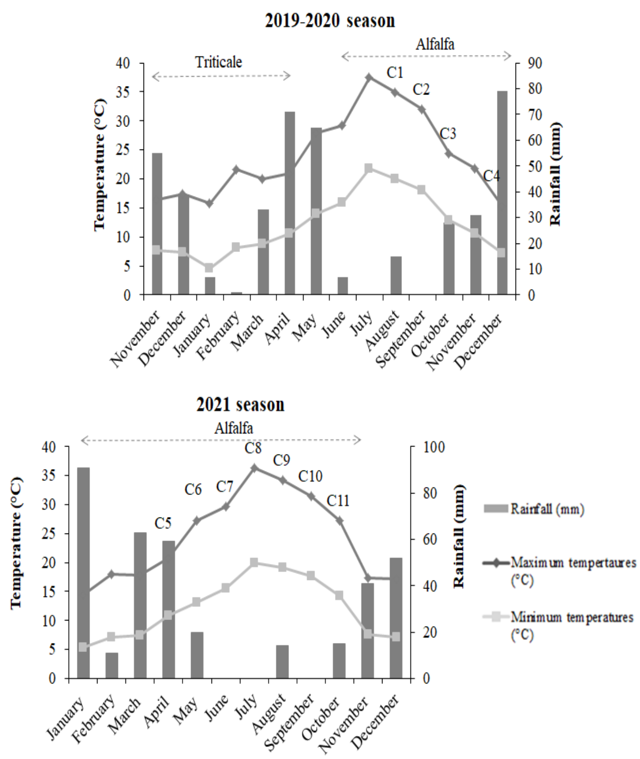

Figure 1. Evolution of climatic parameters (minimum and maximum temperatures and rainfall) during the growing seasons (2019, 2020, and 2021) of triticale and alfalfa

Concerning fertilization, the triticale crop received 150 U ha^{-1} of nitrogen (N). For alfalfa, the crop received 38 U ha^{-1} of nitrogen (N), 46 U ha^{-1} of phosphorus (P), and 50 U ha^{-1} of potassium (K). The nutrients were applied as ammonitrate, di-ammonium phosphate (DAP), and soluble potassium sulfate.

Fungal diseases were controlled by the application of azoxystrobin and difenoconazole. Insects (aphids and leaf miners) were controlled with Chlorantraniliprole and Imidachloprid.

Measurements and soil and plant analyzes

Stomatal conductance, chlorophyll content index (CCI), leaf area, and height were determined just before triticale harvest and for each alfalfa cut. Stomatal conductance was measured by a porometer (Leaf Porometer, Model-Sc-1, Decagon Devices). This measurement concerned 5 plants per experimental unit. For each plant, the stomatal conductance was measured in flag leaves of triticale and in middle leaves for alfalfa.

The chlorophyll content index was determined in 15 flag leaves per experimental plot for triticale and 10 leaves for alfalfa using a chlorophyll meter (Opti-Sciences, CCM-300). Leaf area was measured for 10 flag leaves for triticale and for 4 alfalfa plants for each experimental plot using a planimeter (Area Meter, AM300, Bio Scientific Ltd). Height was measured for 10 plants per experimental plot of each studied crop.

The harvest of triticale was done manually at the kernel dough stage. For alfalfa, the cut was carried out at the beginning of flowering (5%). The biomass produced per experimental plot was determined for triticale and each cut of alfalfa. The aerial dry biomass was determined after drying the fresh biomass at 60 °C until constant weight.

The mineral composition of plants after each cut of triticale and alfalfa was determined for each repetition of the studied treatments. The Cl concentration was determined by colorimetry using a continuous flow analyzer (Skalar SAN++, Skalar, Breda, Netherlands) (Cotlove, 1963) and the Na concentration was determined by a flame photometer combined with the continuous flow analyzer (Walinga *et al.*, 1995).

The N and P content was determined using an auto-analyzer (Skalar SAN++, Skalar, Breda, Netherlands), while the K and Mg content was determined by atomic absorption (Varian AA 240, Fast Sequential, air + acetylene flame). The zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) contents were determined using an atomic absorption spectrophotometer (Varian AA 240 FS) according to the method described by Walinga *et al.* (1995). The boron (B) content was determined by colorimetry (UV–Visible Varian) using the spectrometric method with Azomethine H (Berger and Truog, 1939).

Soil samples were taken after the triticale harvest and after each alfalfa cut. The soil sample was taken from the crop line at a depth of 0-30 cm for each experimental plot using an Edelman soil auger with a diameter of 7 cm. It was dried at 40°C for 48 h to determine electrical conductivity (ECs) by extraction (1:5) and nutrient contents. The content of Na was determined by ammonium acetate solution (1 mol l^{-1}, pH=7) (Schollenberger and Simon, 1945) using the absorption spectrophotometer atomic (Varian 240 AA Fast Sequential). Then, the exchangeable sodium percentage in soil (ESP) was calculated by the formula (1) (Richards, 1954):

$$ESP = \frac{[Na+]}{CEC} * 100 \qquad (1)$$

Where $[Na^{+}]$: The exchangeable sodium in soil (meq $100g^{-1}$); CEC: Cation exchange capacity (meq $100g^{-1}$)

***Statistical analysis*:** an analysis of variance ($p \leq 0.05$) was carried out for triticale and for each cut of alfalfa according to the mathematical model of the randomized complete blocks.

In the case of a significant effect of treatment, the differences between the means of different measured parameters were compared by the Student-Newman-Keuls test ($p \leq 0.05$ level). All statistical analyzes were performed using SPSS program (Version 25).

RESULTS

***Evolution of soil salinity* (ECs) *and exchangeable sodium percentage (ESP)*:** Soil salinity decreased with the duration of soil occupation by crops. Therefore, soil salinity decreased significantly from the initial salinity levels of the studied treatments after harvesting triticale (Table 2). For a soil electrical conductivity ECs ≥ 0.8 dS m^{-1}, the decrease was greater than 44% (0.45 dS m^{-1}). On the other side, the soil salinity of the highest ECs treatment after the triticale harvest (1.01 dS m^{-1}) was three times higher than the control (0.27 dS m^{-1}) (Table 2). However, the absence of difference between the soil salinity treatments studied was recorded after the fourth cut of alfalfa (Table 2).

A positive linear relationship between soil electrical conductivity (ECs) and the exchangeable Sodium Percentage (ESP) in soil was recorded (R^2= 0.98). The percentage of ESP before sowing was 6.8% for control. The ESP was 85.8% at the high soil salinity level (2 dS m^{-1}).

A decrease in ESP was recorded during the different production seasons (Table 3). After the harvest of triticale, the ESP of control was 3.68%. However, this percentage exceeded 22% for all soil salinity levels (Table 3). At the first cut of alfalfa, the ESP was less than 20% for different ECs

Table 2. Soil salinity after harvest of triticale and at each cut of alfalfa during the production seasons at the different initial electrical conductivities of soil (ECs).

ECs treatments before sowing (dS m^{-1})			Control (0.3)	0.8	1.5	1.8	2
Crops		**Harvest date**	**ECs at each cut (dS m^{-1})**				
Triticale		Apr.2020	0.27±0.04e	0.45±0.05d	0.59±0.10c	0.75±0.07b	1.01±0.20a
Alfalfa	Cut 1	Aug.2020	0.27±0.02b	0.29±0.04ab	0.31±0.03ab	0.32±0.06ab	0.35±0.04a
	Cut 2	Sep.2020	0.30±0.04b	0.29±0.03b	0.31±0.05b	0.36±0.05b	0.42±0.05a
	Cut 3	Oct.2020	0.30±0.03b	0.28±0.03b	0.31±0.05b	0.31±0.03b	0.36±0.03a
	Cut 4	Dec.2020	0.22±0.02ab	0.21±0.02b	0.23±0.02ab	0.25±0.03a	0.25±0.01a
	Cut 5	Apr.2021	0.26±0.03a	0.25±0.02a	0.24±0.02a	0.26±0.03a	0.28±0.00a
	Cut 6	May.2021	0.29±0.01a	0.29±0.02a	0.28±0.01a	0.29±0.03a	0.29±0.02a
	Cut 7	Jun.2021	0.32±0.04a	0.30±0.04a	0.32±0.06a	0.32±0.04a	0.31±0.03a
	Cut 8	Jul.2021	0.49±0.08a	0.43±0.10a	0.46±0.06a	0.47±0.07a	0.46±0.03a
	Cut 9	Aug.2021	0.37±0.06a	0.41±0.03a	0.42±0.06a	0.39±0.11a	0.34±0.06a
	Cut 10	Sep.2021	0.27±0.03a	0.34±0.08a	0.33±0.06a	0.30±0.04a	0.29±0.02a
	Cut 11	Oct.2021	0.27±0.03a	0.26±0.02a	0.28±0.05a	0.27±0.06a	0.29±0.08a

Data are the means ± standard deviation (n=4). For each harvest/cut, means followed by the same small letters are not significantly different

Table 3. Exchangeable sodium percentage in soil (ESP) after harvest of triticale and at each cut of alfalfa during the production seasons at the different initial electrical conductivities of soil (ECs).

ECs treatments before sowing (dS m^{-1})			Control (0.3)	0.8	1.5	1.8	2
EXP (%)			**6.8**	**41.6**	**63.3**	**78.5**	**85.8**
Crops		**Harvest date**	**ESP at each cut (%)**				
Triticale		Apr.2020	3.68±1.6c	22.83±7.7b	28.44±12.1b	36.74±15.1b	52.31±19.1a
Alfalfa	Cut 1	Aug.2020	4.83±0.6c	6.17±1.3bc	7.04±1.2bc	10.12±3.2b	19.43±5.4a
	Cut 2	Sep.2020	4.86±0.9c	4.84±0.8c	6.29±1.9bc	10.05±3.4b	17.17±6.8a
	Cut 3	Oct.2020	5.89±0.8b	6.06±1.0b	7.53±1.7b	8.74±2.0b	13.58±4.3a
	Cut 4	Dec.2020	4.09±0.2b	4.41±0.9b	4.44±0.7b	6.44±1.9ab	7.78±3.2a
	Cut 5	Apr.2021	4.21±0.4a	4.21±0.4a	4.56±1.0a	5.23±1.1a	5.67±1.3a
	Cut 6	May.2021	5.00±0.5a	5.19±1.0a	5.68±0.8a	5.97±1.0a	6.02±0.2a
	Cut 7	Jun.2021	6.01±0.6a	6.03±0.3a	6.45±0.8a	6.56±1.1a	6.37±0.6a
	Cut 8	Jul.2021	3.70±0.6a	4.05±0.5a	4.30±0.9a	3.85±0.9a	4.84±0.7a
	Cut 9	Aug.2021	5.53±0.5a	6.25±1.1a	6.48±0.4a	6.22±1.5a	7.19±1.6a
	Cut 10	Sep.2021	8.60±2.2a	9.17±1.4a	9.97±2.6a	9.72±1.8a	11.58±3.0a
	Cut 11	Oct.2021	4.05±0.3a	4.11±0.5a	4.94±1.2a	4.49±1.2a	5.61±1.2a

Data are the means ± standard deviation (n=4); For each harvest/cut, means followed by the same small letters are not significantly different; *Biomass production*

treatments. From the 5th cut of alfalfa, the ESP was around 5% for all ECs levels (Table 3).
The negative impact of soil salinity on the biomass production of triticale crop was significant (R^2=0.92). Thus, the dry biomass of triticale produced by control (0.3 dS m^{-1}) was around 11.5 t ha^{-1} (Table 4). It was reduced significantly by the soil salinity. The decreases were 30% and 62% at a soil salinity of 0.8 and 2 dS m^{-1}, respectively, compared to the control (Table 4). The increase in soil salinity did not lead to a decrease in biomass production for all alfalfa cuts. Also, the highest biomass was recorded during the 5th (9.58 t ha^{-1}) and 6th (9.95 t ha^{-1}) cuts. However, the lowest cut production was related to the fourth cut (3.26 t ha^{-1}) (Table 4).
The studied crops were able to eliminate 1433 kg ha^{-1} of NaCl for a starting soil salinity of 2 dS m^{-1} in both seasons (Table 5).
The NaCl uptake was relative to the produced biomass and the Na and Cl concentration in this biomass (Table 5). For the triticale, the highest NaCl uptake of 108 kg ha^{-1} was recorded at a soil salinity of 0.8 dS m^{-1}. For the high level of salinity ECs= 2 dS m^{-1}, the NaCl uptake was 46.31 kg ha^{-1}.
For alfalfa, the highest NaCl uptake (≥ 145 kg ha^{-1}) was recorded at a salinity of 2 dS m^{-1} during the 2nd, 3rd, and 6th cut (Table 5).
The chlorophyll content index measured on the studied crops was not influenced by the different soil salinity levels during the both seasons (Table 6). However, the negative effect of salinity on stomatal conductance, stem height, and leaf area was noticed only on the triticale at ECs ≥ 0.8 dS m^{-1} (Table 6). At the initial soil electrical conductivity of 2 dS m^{-1}, stomatal conductance, stem height, and leaf area decreased by 65%,

Table 4. Total aerial dry biomass (t ha^{-1}) of triticale and alfalfa after each cut during the production seasons at different electrical conductivities of soil (ECs).

ECs treatments before sowing (dS m^{-1})			**Control (0.3)**	**0.8**	**1.5**	**1.8**	**2**
Crops		**Harvest date**	**Dry biomass at each cut (t ha^{-1})**				
Triticale		Apr.2020	11.53±2.4a	8.11±1.7b	7.49±1.7bc	5.68±1.1cd	4.41±1.0d
Alfalfa	Cut 1	Aug.2020	4.37±0.7a	3.62±0.6b	4.79±0.9a	4.79±0.8a	4.74±0.9a
	Cut 2	Sep.2020	5.49±0.6a	5.62±0.8a	5.68±0.9a	6.71±1.4a	6.55±1.4a
	Cut 3	Oct.2020	4.10±0.5b	4.13±0.1b	4.36±0.9ab	4.62±1.2ab	5.48±1.3a
	Cut 4	Dec.2020	3.12±0.9a	2.93±0.3a	3.24±0.8a	3.44±0.7a	3.59±0.6a
	Cut 5	Apr.2021	9.01±2.1a	9.54±1.8a	9.54±2.0a	10.14±1.6a	9.66±2.7a
	Cut 6	May.2021	10.74±1.4a	8.50±2.1a	10.06±2.5a	9.87±2.1a	10.56±2.4a
	Cut 7	Jun.2021	6.89±1.2a	6.75±1.2a	7.31±1.3a	7.24±0.9a	7.59±0.5a
	Cut 8	Jul.2021	4.51±0.4a	3.70±0.7a	4.77±0.7a	4.17±1.4a	5.00±1.5a
	Cut 9	Aug.2021	4.65±1.3a	3.89±0.5a	4.48±1.1a	5.14±0.9a	5.52±1.6a
	Cut 10	Sep.2021	6.03±1.0a	5.83±1.8a	6.03±1.5a	5.99±0.8a	7.45±0.4a
	Cut 11	Oct.2021	4.40±1.1a	3.71±0.5a	4.70±1.4a	4.72±1.6a	5.14±1.7a

Data are the means ± standard deviation (n=4); For each harvest/cut, means followed by the same small letters are not significantly different; NaCl-removal capacity of crops

Table 5. NaCl uptake (kg ha^{-1}) of triticale and alfalfa at each cut during the production seasons at different electrical conductivities of soil (ECs).

ECs treatments before sowing (dS m^{-1})			**Control (0.3)**	**0.8**	**1.5**	**1.8**	**2**
Crops		**Harvest date**	**NaCl uptake at each cut (kg ha^{-1})**				
Triticale		Apr.2020	96.07±27.8ab	108.08±34.3a	76.31±34.3bc	59.98±15.8cd	46.31±0.8d
Alfalfa	Cut 1	Aug.2020	74.03±13.7a	55.26±10.8a	67.95±13.3a	63.44±12.2a	65.71±6.7a
	Cut 2	Sep.2020	122.95±13.9b	124.25±15.7b	125.19±16.6b	139.79±24.8b	162.27±11.4a
	Cut 3	Oct.2020	103.03±12.9b	107.61±11.9b	115.53±26.8ab	123.60±26.9ab	145.28±27.5a
	Cut 4	Dec.2020	66.92±22.5a	55.24±8.1a	71.55±20.1a	73.47±17.5a	85.00±22.7a
	Cut 5	Apr.2021	118.39±39.0a	137.37±31.6a	129.53±31.0a	142.66±28.9a	138.58±39.7a
	Cut 6	May.2021	128.21±20.4a	103.65±24.2a	138.95±44.3a	131.05±22.0a	158.74±67.3a
	Cut 7	Jun.2021	111.70±25.3a	112.85±31.0a	111.52±23.4a	127.64±37.4a	131.53±18.3a
	Cut 8	Jul.2021	64.19±12.9a	52.37±20.3a	70.08±17.7a	65.37±24.1a	82.41±30.8a
	Cut 9	Aug.2021	71.15±22.1a	58.08±17.5a	66.08±24.8a	86.82±19.9a	91.39±30.5a
	Cut 10	Sep.2021	93.52±18.9a	88.52±24.8a	85.46±22.7a	100.73±21.9a	109.18±13.6a
	Cut 11	Oct.2021	79.60±37.8a	59.80±25.0a	73.18±24.8a	84.62±31.5a	104.84±42.1a
	Total uptake		1130±199b	1063±125b	1131±222b	1199±187b	1433±132a

Data are the means ± standard deviation (n=4); For each harvest/cut, means followed by the same small letters are not significantly different; Chlorophyll content index, stomatal conductance, stem height, and leaf area

37%, and 53%, respectively, compared to the control (ECs= 0.3 dS m^{-1}).

***Nutrient status of triticale and alfalfa*:** Concerning the nutritive status of triticale, the contents of N, P, K, Mg, and Ca were invariable for the different levels of soil salinity (Table 7). The N content was around 1.41%, 0.13% for P, 1.10% for K, 0.15% for Mg, and 0.28% for Ca.

For alfalfa, the N, P, and K contents were not influenced by the soil salinity during the both studied seasons (Table 7). The N content was 3.59%, 0.35% for P, and 1.96% for K. In contrast, Mg and Ca concentrations in alfalfa decreased with increasing soil salinity levels. A decrease of 22% for Mg and 14% for Ca was recorded at a soil salinity of 1.01 dS m^{-1} compared to the control (Table 7). However, this variability

Table 6. Chlorophyll content index (CCI), stomatal conductance (CS), stem height, and leaf area of triticale and alfalfa during the production seasons at the different electrical conductivities of soil (ECs).

ECs treatments before sowing (dS m^{-1})		Control (0.3)	0.8	1.5	1.8	2
Measured parameter	Stage	Triticale (Nov 2019 to Apr 2020)				
CCI	Harvest	1.30±0.2a	1.30±0.1a	1.30±0.1a	1.27±0.1a	1.35±0.2a
CS (mmol.$m^{-2}s^{-1}$)		29.98±8.3a	17.84±5.9b	15.69±4.9b	14.32±3.9b	10.52±3.3c
Stem height (cm)		94.20±12.0a	83.23±6.8b	78.41±9.3c	74.25±7.9d	59.60±11.0e
Leaf area (dm²)		0.19±0.1a	0.14±0.0b	0.12±0.0c	0.12±0.0c	0.09±0.0d
		Alfalfa (June to Dec 2020)				
CCI	Means	1.08±0.1a	1.06±0.1a	1.09±0.1a	1.08±0.1a	1.08±0.1a
CS (mmol$m^{-2}s^{-1}$)	(cut 1 to cut 4)	44.41±12.1a	43.55±12.3a	45.93±14.6a	46.61±14.1a	44.92±14.4a
Stem height (cm)		55.63±8.4b	53.49±7.5c	56.66±8.3ab	57.23±8.6ab	58.37±7.8a
Leaf area (dm²)		2.08±0.8a	1.91±0.9a	1.95±0.8a	2.07±0.8a	1.98±0.9a
		Alfalfa (Jan to Oct 2021)				
CCI	Means	1.12±0.1a	1.15±0.1a	1.12±0.1a	1.13±0.1a	1.12±0.1a
CS (mmol$m^{-2}s^{-1}$)	(cut 5 to cut 11)	40.69±18.8a	42.58±15.7a	42.00±18.2a	42.94±17.5a	40.14±17.6a
Stem height (cm)		72.99±17.8a	71.39±18.0a	72.17±17.6a	73.38±17.1a	72.44±16.2a
Leaf area (dm²)		2.28±1.7a	2.36±1.6a	2.22±1.3a	2.19±1.3a	2.36±1.6a

Data are the means ± standard deviation (n=60 for chlorophyll content index of triticale and n=40 for CCI of alfalfa, n=20 for stomatal conductance, n=40 for stem height, and n=40 for leaf area of triticale and n=16 for leaf area of alfalfa). For each studied crop and measured parameter, means followed by the same letters are not significantly different.

Table 7. Nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca) contents (%) in the plants of triticale and alfalfa during the production seasons for different conductivity levels of soil (ECs).

ECs treatments before sowing (dS m^{-1})		Control (0.3)	0.8	1.5	1.8	2
Analyzed element	Stage	Triticale (Nov 2019 to Apr 2020)				
N (%)	Harvest	1.39±0.13a	1.33±0.14a	1.43±0.09a	1.50±0.21a	1.39±0.11a
P (%)		0.13±0.01a	0.13±0.03a	0.14±0.02a	0.14±0.03a	0.12±0.01a
K (%)		1.06±0.09a	1.11±0.04a	1.09±0.12a	1.12±0.12a	1.11±0.07a
Mg (%)		0.16±0.01a	0.15±0.01a	0.16±0.02a	0.15±0.02a	0.14±0.01a
Ca (%)		0.27±0.05a	0.30±0.04a	0.28±0.05a	0.31±0.07a	0.26±0.05a
		Alfalfa (June to Dec 2020)				
N (%)	Means	3.41±0.50a	3.39±0.53a	3.42±0.42a	3.35±0.40a	3.29±0.36a
P (%)	(cut 1 to cut 4)	0.35±0.04a	0.35±0.04a	0.36±0.04a	0.35±0.04a	0.35±0.04a
K (%)		2.00±0.32a	2.05±0.34a	2.01±0.33a	2.07±0.39a	2.14±0.41a
Mg (%)		0.60±0.10a	0.57±0.08ab	0.57±0.09ab	0.51±0.09bc	0.47±0.08c
Ca (%)		2.26±0.35a	2.20±0.29ab	2.11±0.28ab	1.99±0.33b	1.95±0.33b
		Alfalfa (Jan to Oct 2021)				
N (%)	Means	3.86±0.50a	3.69±0.41a	3.88±0.50a	3.75±0.52a	3.86±0.60a
P (%)	(cut 5 to cut 11)	0.34±0.06a	0.34±0.07a	0.34±0.06a	0.35±0.06a	0.33±0.09a
K (%)		1.89±0.43a	1.88±0.43a	1.81±0.38a	1.95±0.52a	1.80±0.34a
Mg (%)		0.57±0.12a	0.57±0.10a	0.57±0.12a	0.55±0.18a	0.51±0.10a
Ca (%)		2.18±0.32a	2.22±0.48a	2.15±0.33a	2.14±0.44a	2.13±0.51a

Data are the means ± standard variation (n=4); For each studied crop and analyzed element, means followed by the same letters are not significantly different

Table 8. Zinc (Zn), copper (Cu), manganese (Mn), iron (Fe), and boron (B) contents (mg kg^{-1}) in the plants of triticale and alfalfa during the production seasons for different conductivity levels of soil (ECs).

ECs treatments before sowing (dS m^{-1})		Control (0.3)	0.8	1.5	1.8	2
Analyzed element	Stage	Triticale (Nov 2019 to Apr 2020)				
Zn	Harvest	13.19±1.4a	12.46±1.4a	12.93±0.8a	13.15±1.4a	11.90±1.6a
Cu		7.68±1.1a	7.10±0.5a	8.10±1.2a	8.16±1.4a	7.30±0.9a
Mn		48.23±3.6a	53.48±6.7a	53.24±7.0a	51.98±6.4a	54.95±6.2a
Fe		53.61±13.5a	64.38±10.0a	60.66±20.0a	69.10±24.2a	75.38±1.8a
B		3.10±1.1a	4.34±1.4a	3.50±1.1a	3.91±1.2a	4.28±1.8a
		Alfalfa (June to Dec 2020)				
Zn	Means	21.07±4.1a	20.64±3.2a	20.41±4.1a	21.81±6.0a	21.54±3.7a
Cu	(cut 1 to cut 4)	11.30±1.6a	11.09±1.1a	11.04±2.0a	11.01±2.2a	12.01±1.1a
Mn		35.88±6.8b	37.21±8.0ab	41.21±8.2ab	38.78±8.0ab	43.22±11.1a
Fe		297.13±122a	266.25±56.9a	307.25±115.5a	274.88±73.9a	270.55±152a
B		60.16±13.5a	63.73±13.0a	57.38±10.0a	57.37±13.9a	60.79±11.4a
		Alfalfa (Jan to Oct 2021)				
Zn	Means	23.03±4.4a	23.21±7.9a	22.28±5.7a	22.89±5.4a	23.72±5.2a
Cu	(cut 5 to cut 11)	12.37±4.2a	10.96±2.1a	12.13±5.0a	12.32±4.6a	14.12±7.0a
Mn		36.11±20.4a	37.17±24.5a	36.25±18.1a	36.17±17.2a	36.73±12.6a
Fe		201.13±89.6a	185.80±61.0a	201.12±81.1a	200.45±76.4a	187.98±82.9a
B		51.29±12.0a	55.47±15.1a	50.18±13.1a	52.43±14.0a	51.00±10.9a

Data are the means ± standard variation (n=4); For each studied crop and analyzed element, means followed by the same letters are not significantly different

was not recorded during the 2021 season. The Mg and Ca contents of alfalfa plants were 0.55% and 2.16%, respectively, for all the treatments studied.

Table 9. Key finding of the potential of a forage cropping system based on triticale and alfalfa on the desalinization of a calcareous soil.

Measured parameters	Key results
Soil salinity (ECs)	• After harvesting triticale, the decrease was greater than 44% for an ECs≥ 0.8 dS m^{-1} (1:5 water extraction) • No difference between the soil salinity treatments after the 4th cut of alfalfa.
Exchangeable Sodium Percentage (ESP) in soil	• From the 5th cut of alfalfa, the ESP was around 5% for all ECs levels.
Biomass production	• The decrease in biomass production was only recorded with triticale crop.
NaCl-removal capacity	• The studied crops were able to eliminate 1433 kg ha^{-1} of NaCl for an ECs of 2 dS m^{-1}.
Nutrient status of triticale and alfalfa	• N, P, and K contents were invariable for both studied crops under different ECs levels • Mg and Ca concentrations in alfalfa decreased with increasing ECs. • Micronutrient contents of triticale were not influenced by the different ECs levels. • An increase on Mn content of alfalfa was recorded at ECs=2 dS m^{-1} only during the 2020.

Concerning micronutrient, the Zn, Cu, Mn, Fe, and B contents of triticale plants were not influenced by the different levels of soil salinity (Table 8). For alfalfa, the variation of Zn, Cu, Fe, and B contents with salinity levels was not noticed during the both studied seasons. However, an increase on Mn content (+20% compared to the control) was recorded at a salinity level ECs=2 dS m^{-1} only during the 2020 season (Table 8). The key funding of this research are summarized in Table 9.

DISCUSSION

Based on this investigation, the use of triticale and alfalfa has proven to be efficient in improving the quality of soil containing salt. This is indicated by soil salinity of soil (ECs) and its exchangeable sodium percentage (ESP). These parameters decreased significantly during the soil occupation by the tested crops according to Tables 2 and 3. For triticale, the decline in the ECs at harvest (over -44%) confirms the result reported by Zhang et *al.* (2023) on this crop. After the 4th cut of alfalfa, the initial ECs levels became similar to the non-saline control (0.28 dS m^{-1}) for the highest tested ECs (2 dS m^{-1}) (Table 2). Furthermore, the soil desalinization using triticale and alfalfa was represented by significant reductions in ESP (Table 3). Indeed, the highest initial ESP level (85.8%) reached similar values to the uninfected control (ESP=6.8%) after the 4th cut of alfalfa. These low soil ESP values will help limit soil degradation (Leogrande and Vitti, 2018). The role of alfalfa in soil desalinization was confirmed in a previous study (Cao *et al.*, 2012). It was explained by Na removing from the soil (Shah *et al.*, 2022). Previous studies reported

that increased Na^+ and Cl^- concentrations in shoots and roots were considered as a mechanism of salt tolerance in alfalfa and triticale (Kankarla *et al.*, 2019; Al-Farsi *et al.*, 2020). This salt-removing capacity was related to the produced biomass (Hasanuzzaman *et al.*, 2014) and Na and Cl concentration in the plant. Indeed, the succession of triticale and alfalfa (11 cuts) was able to remove 1433 kg ha^{-1} of NaCl at an initial soil salinity of 2 dS m^{-1} (Extract 1:5) according to Table 5. These results shed light on the ability of triticale and alfalfa to restore salinized soil and ensure its sustainability, particularly in arid areas where low rainfall is insufficient to ensure salt leaching.

On the other side, the negative impact of the salinity on dry fodder biomass was recorded in triticale as the first crop of the cropping succession (Table 4). The significant decrease in the biomass of triticale (-62%) compared to the control (11.53 t ha^{-1}) at the most saline soil (ECs= 2 dS m^{-1}) can be explained by the low photosynthetic activity due to the reduction in stomatal conductance (Table 6). This reduction was also reported by El-Metwally *et al.* (2019) for triticale plants. A similar negative influence of salinity on leaf area and stomatal conductance reported in Table 6 was described by Hasanuzzaman *et al.* (2013). For alfalfa, the absence of biomass decline in the residual soil salinity after the triticale harvest (up to ECs=1.01 dS m^{-1}) has proven the resistance of this crop to saline conditions. These results suggest that the inclusion of triticale and alfalfa in the forage cropping system will help ensure livestock feeding in saline conditions in arid and semi-arid areas. The introduction of these forage crops was also recommended by Guerchi *et al.* (2023) and Zhang *et al.* (2023). In addition, the profitability of these forage crops was positive even at high salinity level (ECs=2 dS m^{-1}). It was around 186$ ha^{-1} for triticale as the first crop and 1045$ ha^{-1} per cut for alfalfa (data not shown).

Concerning the nutrient status of the triticale and alfalfa, the invariable N , P, and K contents noticed at saline conditions (up to ECs=2 dS m^{-1}) (Table 7) revealed that fertilization based on the requirements in N, P, and K adopted in this study is suitable in the case of saline stress in calcareous soil. Additionally, the inclusion of alfalfa in a cropping system as a legume will help reduce N supply and enhance soil fertility (Ghosh *et al.*, 2020). However, the decrease in the Mg and Ca content of alfalfa observed with soil salinity during the first studied season (Table 7) can be explained by the antagonism between Na^+ ions and the divalent cations Ca^{2+} and Mg^{2+} (Machado and Serralheiro, 2017; Zörb *et al.*, 2018). The same finding was reported for different varieties of alfalfa at salt stress (El-Sharkawy *et al.*, 2017; Bhattarai *et al.*, 2021). The calcium was reported as an important element in salt stress. It helps in preserving membrane integrity, signaling in osmoregulation, and influencing K^+/Na^+ selectivity (Ashrafi *et al.*, 2018). Furthermore, the decline in Mg^{2+} concentration under salt conditions could be a result of stress and membrane permeability (El-Sharkawy *et al.*, 2017). Therefore, the nutrient imbalance of Ca and Mg can be prevented using the foliar spray of these macronutrients, particularly in the tested calcareous soil (Kumari *et al.*, 2022). Concerning the micronutrients, the contents of Zn, Cu, Mn, Fe, and B on triticale were invariable at different levels of the ECs (Table 8). Thus, the high contents of Na and Cl in this studied soil did not disturb the absorption of the micronutrients by triticale. In contrast, Akgün *et al.* (2011) reported a negative effect of the soil salinity on the micronutrient contents of triticale plants. For alfalfa, the increase in Mn content during the first production season (2020) (Table 8) was similar to the results reported by Ferreira *et al.* (2015).

***Conclusion*:** The present investigation revealed that the insertion of triticale and alfalfa in the forage cropping system is an efficient solution for salt-stressed soils in arid regions. The high NaCl removal capacity of the tested crops helps alleviate soil salt stress, enhance soil quality, and improve crop production. Thus, triticale and alfalfa can be considered tolerant species and replaced sensitive crops like corn in a sustainable forage cropping system. The nutrient status of these crops was invariable in saline-sodic soil, particularly for macronutrients (N, P, and K). A foliar spray of Ca and Mg to alfalfa seems to be requested to avoid nutrient disruption due to saline-sodic conditions in calcareous soil.

***Authors contributions statement*:** N. Darrhal performed the experiments, Wrote the paper; S. Drissi Analyzed and interpreted the data; Wrote the paper; F. Amlal contributed reagents, materials, analysis tools or data, prepared the draft; A. Mesfioui conceived and designed the Experiments; K. Dhassi prepared and reviewed the draft; A. Asfers, R. El Kourdi contributed reagents, materials, analysis tools or data; M. Mounsif, A. Ait Houssa Conceived and designed the experiments

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